REMARKS

Claims 1, 11, 25, 26, and 30 have been amended to clarify the invention and better define the invention over the art. No new matter has been entered.

The allowability of the subject matter of claims 8-10 and 22-24 is noted, with thanks.

Turning first to the rejection of claims 26-29 as indefinite, independent claim 26 has been amended to clarify that the claimed method is a method of "providing an electrical connection to a thermocouple sensing junction." It is believed that this amendment is sufficient to traverse the indefiniteness rejection of claim 26, as well as claims 27-29 depending therefrom.

Turning now to the art rejections, and considering first the rejection of claims 1, 3, 6-7, 25 and 30 as anticipated by Moore, U.S. Patent No. 4,698,454 ("Moore"), claim 1, as amended, requires the presence of "a metallic cup electrically connected to a thermocouple sensing junction." Element 52, which the Examiner cited as anticipating a "cup/contact element" is not metallic, but rather, is, an insulating ring (column 3, line 46), fabricated from "high temperature glasses, fluxes, and refractory materials" (column 4, lines 18-20). Since Moore does not teach the presence of "a metallic cup electrically connected to a thermocouple sensing junction," Moore cannot be said to anticipate claim 1, nor claims 3, 6, and 7 that depend therefrom, which are patentable for the reasons given above with respect to claim 1, as well as for their own additional limitations. Regarding claim 25, this claim, as amended, requires the presence of "a metallic contact element electrically coupled to said thermocouple sensing junction." As argued above with respect to claim 1, this element is not taught in Moore, and therefore Moore cannot be said to anticipate claim 25. Regarding claim 30, this claim, as amended, requires "a metallic connecting portion for positioning a thermocouple cable such that it electrically

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connects to said thermocouple sensing junction." This connecting portion could be, e.g., element 3 in Applicant's Figure 1, which positions the thermocouple cable 14 such that it electrically connects to the thermocouple sensing junction via elements 5 and 6. No such metallic connecting portion is taught, disclosed, or suggested by Moore. Therefore, Moore cannot anticipate claim 30.

Considering now the rejection of claims 1, 3, 4, 10, 11, 14, 15, 17-19, 26, 28 and 29 as anticipated by Polye et al., U.S. Patent No. 2,483,350 ("Polye et al."), claim 1, as amended, requires "a metallic cup electrically connected to a thermocouple sensing junction." Element 1 of Figure 1 of Polye et al., which the Examiner refers to as a "cup/contact element," is in no way electrically connected to junction 17, nor to either wire 5, 6 leading to junction 17. Thus, Polye et al. cannot be said to anticipate claim 1, nor claims 3, 4, or 10 depending therefrom, which are patentable for the reasons given above with respect to claim 1, as well as for their own additional limitations. Regarding claim 11, this claim, as amended, requires the presence of a "metallic contact element electrically connected to a thermocouple sensing junction." As discussed with respect to claim 1, Polye et al. does not teach, disclose, or suggest this element, and therefore cannot be said to anticipate claim 11, nor claims 14, 15, and 17-19 depending therefrom, which are patentable for the same reasons given above with respect to claim 11, as well as for their own additional limitations. Regarding claim 26, this claim, as amended, requires "a thermocouple junction box having a stud fixedly disposed in relation to a metallic contact element electrically connected to a thermocouple sensing junction." As explained above with regard to claims 1 and 11, no such element is taught, disclosed, or suggested by Polye et al., and Polye et al. therefore cannot anticipate claim 26, nor claims 28 and 29 that

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depend therefrom and are patentable for the reasons given above with respect to claim 26, as well as for their own additional limitations.

Considering now the rejection of claims 6-7 and 20-21 as obvious over Polye et al. in view of Moore, these claims are patentable for the reasons given above with respect to claims 1 and 11, from which they respectively depend, as well as for their own additional limitations.

Considering now the rejection of claims 5, 16, and 27 as obvious over Polye et al., these claims are patentable for the reasons given above with respect to claims 1, 11 and 26 from which they respectively depend, as well as for their own additional limitations.

Regarding the rejection of claim 12 as obvious over Polye et al. in view of Champoux et al., U.S. Patent 4,202,242 ("Champoux et al."), this claim is patentable for the reasons given above with respect to claim 11, as well as for its own additional limitations.

Turning now the rejection of claim 13 as obvious over Polye et al, this claim is patentable for the same reasons given above with respect to claim 11, as well as for its own additional limitations.

Accordingly, it is respectfully submitted that all of the currently pending claims, as amended, are allowable. Thus, allowance at an early date is earnestly solicited.

The objection to the Information Disclosure Statement is not understood. Applicants filed copies of the cited references with the Information Disclosure Statement of October 31, 2003 (see the attached postcard receipt). For the Examiner's review, duplicate copies of these references accompany this Amendment.

In the event that the Examiner deems personal contact for further disposition of the this case desirable, the Examiner is invited to call the undersigned attorney at 520-882-7623.

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In the event there are any fee deficiencies or additional fees are payable, please charge them (or credit any overpayment) to our Deposit Account Number 08-1391.

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CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as First Class Mail in an envelope addressed to: MAIL STOP AMENDMENTS, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on July 27, 2004, at Tucson, Arizona.

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WILKERSON INSTRUMENT CO., INC

SERVICE
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The Wilkerson Transmitter

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E-Commerce: The Instrumentation Market

E-Commerce presents a major challenge to all sensor and instrumentation manufacturers, as it opens up an exciting new channel for distribution. Although e-commerce is still in the development phase, the general public's perceptions of the Internet and the way it can be used to conduct day to day business is becoming more and more accepted. This is, at least in part, due to the progress in technologies enabling major improvements in the e-commerce supply process.

Frost and Sullivan, an international marketing consulting firm that monitors a broad spectrum of instrumentation markets for business trends, has recently published research into the implementation of e-commerce in the instrumentation market in Europe. What Frost and Sullivan has learned in the European market should be applicable to the North American market as well.

Improved Efficiencies of E-Commerce

The emergence of the Internet as an alternative sales channel will increase the efficiency of the supply chain. The obvious advantages to conducting business on the Internet is the potential cost savings to both the manufacturer and the customer as a result of these increased efficiencies. The ability of the customer to go on line and compare product specifications, availability, and costs quickly without waiting for phone calls to be returned, quotations to be prepared, and several discussions as to specifications and applications to be completed offer distinct advantages. In addition, when it's time to order, the ease at which orders can be processed via the Internet is obvious.

From the viewpoint of the manufacturer, the chances of receiving and processing orders in a matter of minutes rather than days holds tremendous advantages. Costs are cut significantly in the internal order entry and fulfillment process.

In a day of intense competition and tight margins within the industrial sector, the cost savings offered by e-commerce will drive the instrumentation industry in this direction.

Dramatic Changes in Distribution Networks Likely

From the way we market, sell, specify, buy, and even deliver instrumentation products, eventually, the entire supply chain of the instrumentation industry will be affected by e-commerce. The eventual widespread use of the Internet to buy and sell product will ultimately threaten the survival of local distributors who fail to get on board with their own Internet marketing plans. Distributors will also need to take on new roles in the marketplace to survive. For example, a distributor may redirect some of his efforts to become consultants working with both the customers and the manufacturers in providing product support and applications engineering. The result will be distributors who are true solutions providers rather than simply a product sales outlet. Many forward thinking instrumentation distributors are already addressing these areas.

Conclusions

"On line sales of industrial instrumentation products are forcast to grow dramatically over the coming years, as customers graduate towards this new and efficient sales channel." –V. Whiting - Frost and Sullivan

The e-commerce market in instrumentation is still in its infancy and has not quite reached a period of exponential growth. However, with more and more forward looking manufacturers currently developing their on line strategies to include web sites which include order placement capabilities, Frost and Sultan expects dramatic on line revenue growth of around 147% per year during the period 2003 through 2005.

Wilkerson Instrument Company, Inc.

Some time ago, Wilkerson Instrument Company recognized the market direction and has now developed a web site featuring products manufactured by Wilkerson Instrument Company as well as other fine instrumentation manufacturers. Technical documents for all products can be viewed and printed from the web site. Customers may purchase over the web site by credit card or purchase order. To view our website, go to www.wici.com.

Quotes Of The Day:

"In matters of style, swim with the current; in matters of principle, stand like a rock." -Thomas Jefferson

"The most damaging phrase in the language is: It's always been done that way." - Rear Admiral Grace Hopper

"I shall adopt new views as fast as they shall appear to be true views." - Abraham Lincoln

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Flawless (Almost) Thermocouple Circuits

Temperature measurements have often been a challenge for instrument engineers. Advanced technologies requiring more and more accurate temperature measurements are not making the challenges any less difficult. Traditionally, when high accuracy is important, RTDs are often chosen over thermocouples as the temperature sensor. However, there are circumstances where the thermocouple is the only possible choice. RTDs offer a limited temperature range and are much more sensitive to vibration and mechanical shock. As accuracy requirements become more important, it is increasingly important that we take care in the design and maintenance of thermocouple circuits to assure the most accurate sensing possible.

Inherent Problems

Thermocouples by nature have a few inherent problems. First of all, the inherent inaccuracy of thermocouples, due to variables in the alloys of metals used in manufacturing, are considerable with most calibrations. Secondly, many people use thermocouple extension wire between the thermocouple sensor and the instrumentation used for indication or control. This adds additional error to the circuit. Once the thermocouple signal is at the measuring instrument, the signal requires a stable, known reference junction. In addition, thermocouples are subject to secondary junctions, ground loops, as well as electrical noise. These problems can, for the most part, be avoided if simple precautions are used in designing and maintaining your thermocouple sensor circuit.

Secondary Junctions

One of the major sources of errors in thermocouple circuits is secondary junctions. Secondary junctions may be avoided by minimizing the number of connection points in the thermocouple extension wire. When using thermocouple extension wire, it is always best to have only one run or length of wire, avoiding terminal blocks and connectors. Always make sure that the thermocouple extension wire makes no sharp bends and is free of kinks that may cause a short which would result in a secondary junction. High temperature thermocouple wire may be insulated with fiberglass or ceramic fiber material that is easily abraded. Avoid abrasion which exposes the conductors. This can lead to secondary junctions. When connections are absolutely necessary, make sure the alloys of the connector or terminal block is a match with the alloy of the thermocouple. Even thermocouple alloy connectors may introduce small amounts of error. In addition, be sure that any connection is made in an area of relatively constant temperature to avoid temperature gradients across connection points. Secondary junctions along the thermocouple extension wire path and at connection points may be avoided completely by using a thermocouple transmitter mounted at the sensor. This eliminates the need for thermocouple extension wire altogether.

Reference Junctions

Reference Junction errors are more difficult to eliminate in the field because the reference junction is usually a part of the measuring instrument. Of course, under ideal circumstances, we can use an ice bath or constant temperature oven to create a stable and constant reference junction, but these are practical only in the laboratory. Therefore, the choice of instrumentation is the best way to control these errors. When choosing the instrument, look at the specification for "Reference Junction Compensation Accuracy". RJC Accuracy is sometimes stated as a part of the total instrument accuracy. Therefore, you should look for an instrument that has either a RJC Accuracy of ±.5 degrees C. or better, or a total accuracy of ±.1 % of Span. Also, when choosing an instrument, look for the location of the Reference Junction Compensator (Cold Junction Compensator). This is usually a thermistor or solid state sensor and ideally it is found as near as possible to the thermocouple input terminals on the measuring instrument. This is important because this is the point at which the thermocouple alloy extension wire is changing to a copper circuit within the instrument. This is the exact location where the reference junction compensation should take place to avoid errors.

Keeping an Accurate System

Once you have done all you can to assure accurate measurements using thermocouples, you must maintain the system with scheduled calibration checks of both the sensor, the extension wire and the instrument. Most of us know to check instrument and sensor calibrations on a regular basis. What many of us forget is the thermocouple extension wire. Since it is of thermocouple alloy material, it is subject to the same calibration drift problems as the thermocouple itself. The wire should be checked by comparing the output of the wire attached to a precalibrated sensor using an accurate, calibrated indicator.

As with many of the inherent problems with thermocouples, thermocouple extension wire calibration drift problems can be eliminated with the use of thermocouple transmitters.

When checking the calibration of the measuring instrument, always follow the manufacturers instructions which will include allowing the instrument to "warm up" after applying power. This allows the reference junction compensation circuit to stabilize and avoids adding in any additional reference junction error.

EAL

European cooperation for Accreditation of Laboratories

Publication Reference **EAL-G31**

Calibration of Thermocouples

PURPOSE

This document has been produced by EAL to improve the harmonisation in thermocouple calibration. It provides guidance to national accreditation bodies to set up minimum requirements for the calibration of thermocouples and gives advice to calibration laboratories to establish practical procedures and the calculation of uncertainties.

Authorship

This document has been revised by EAL Committee 2 (Calibration and Testing Activities), based on the draft produced by the EAL Expert Group 'Temperature and Humidity'.

Official language

The text may be translated into other languages as required. The English language version remains the definitive version.

Copyright

Guidance Publications

This document represents a consensus of EAL member opinion and preferred practice on how the relevant clauses of the accreditation standards might be applied in the context of the subject matter of this document. The approaches taken are not mandatory and are for the guidance of accreditation bodies and their client laboratories. Nevertheless, the document has been produced as a means of promoting a consistent approach to laboratory accreditation amongst EAL member bodies, particularly those participating in the EAL Multilateral Agreement.

Further information

For further information about this publication, contact your National member of EAL:

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0 Scope

0.1 This guidance document has been written to meet the need for a basic advisory document for laboratories undertaking the calibration of thermocouples. It is valid primarily for thermocouple types standardised in accordance with temperature-emf reference tables EN 60584-1 : 1996 and covering the temperature range -200 °C to +1600 °C, the calibrations being carried out in terms of the International Temperature Scale of 1990 (ITS-90). Although most of the topics covered may apply equally to other 'non-standard' thermocouples there may be other important considerations, outside the scope of these guidelines, that may have to be taken into account.

1 Introduction

1.1 A thermocouple consists of two dissimilar conductors connected together at the measuring (or 'hot') junction, the other (reference or 'cold') ends being connected either directly or by some suitable means, to a device for measuring the thermo-electromotive force (emf) generated in the circuit.

1.2 The electromotive force (emf) generated by a thermocouple is a function of the temperature difference between the hot and cold junctions but, more specifically, it is generated as a result of the temperature gradients which exist along the lengths of the conductors. Effective measurements and calibrations are possible only if the hot and cold junctions are maintained in isothermal regions and at a depth sufficient to overcome heat losses (or gains), thereby ensuring that each junction actually reaches the temperature of its environment.

1.3 The magnitude of the emfs depends on the materials of the conductors used for the thermocouple and their metallurgical condition. Subsequent changes in the material composition and condition caused by contamination, mechanical strain, or thermal shock, also influence and modify the emf and an associated calibration. However, any such change is influential only if it is located within the region of a temperature gradient and is not necessarily detectable by recalibration if, for example, a degraded length of conductor is located within the isothermal region of a calibration bath.

1.4 With time and use, degradation of the thermocouple and its calibration is inevitable and, in the longer term, therefore a scheme of regular checks and eventual replacement should be established and maintained. For base-metal thermocouples, at high temperatures, however, replacement rather than recalibration is recommended.

2 Influences to be taken into account

2.1 When the calibration is carried out, it shall be ensured that effects due to the influences listed below are minimised. These influences shall be taken into account for calculating the uncertainty of measurement stated in the calibration certificate.

2.2 Essential influences are:

- poor contact or heat conduction along the thermocouple (lack of immersion)
- variation of temperature with time and spatial temperature distribution in the thermal source
- temperature variation in the cold (reference) junction
- parasitic thermovoltages, e.g. when an extension or compensating cable or a selector switch is used
- electromagnetic interference
- mechanical stresses or deformations
- inhomogeneities
- oxidation
- alloy effects
- insulation resistance.

These influences are discussed in the following sections.

3 Extension and compensating cables

3.1 If, for practical reasons, the length of a thermocouple has to be increased this shall be made by the use of the correct extension or compensating cable. Extension cable consists of conductors made of nominally the same materials as the thermocouple conductors while compensating cable is made from a different pair of alloys. The cables are manufactured to match the emf/temperature characteristic of the thermocouple itself but over a restricted temperature range, no wider than -40 °C to +200 °C. (Manufacturing tolerances are specified in IEC 584-3.)

3.2 These cables should preferably be connected permanently to the thermocouple. Alternatively, connections to thermocouple wires are often made using special plugs and sockets (also made of compensating alloys). It is important to ensure that these secondary junctions are not located in temperature-gradient regions, and they should be shielded or insulated against draughts, radiation, and *rapid* changes in ambient temperature.

3.3 The uncertainties of measurement associated with the use of extension and compensating leads are usually not as small as those of continuous-wire thermocouples. This is attributable to the minor mismatch of materials and, in practice, difficulties in the measurement of the temperatures of the connections between conductors. The uncertainty of measurement may become similar to that of a continuous-wire thermocouple if the extension or compensating cable is included in the calibration. In this case, the extension or compensating cable is part of the thermocouple and should never be replaced by other wires even of the same type or batch. In order to estimate these uncertainty contributions, it is necessary to use an experimental

method that involves changing the thermal profile by cooling or heating along each or both leads with the hot and cold junctions being maintained at a constant temperature.

4 Reference (cold) junction

4.1 Thermocouple temperature-emf tables have the ice-point, 0 °C, as the reference temperature and this traditional fixed point temperature is preferred for accurate and reliable measurements. It is easily prepared using shaved or flaked ice mixed with water. De-ionised water is best, but in many countries tap-water may be good enough.

4.2 At the reference junction, each thermocouple conductor is soft or hard soldered or twisted together with a copper wire. Intermittent or permanent electrical failure at this connection can be caused by an oxide film forming on the thermocouple (base-metal) conductor or the copper wire. In preparation of the connection, the wire should be lightly cleaned with a fine abrasive paper. Each junction of wires should be insulated and the wires mounted in a light close-fitting sheath before insertion in ice/water baths. The copper wires should be taken from the same manufacturing source. Automatic cold-junction devices are used especially when large numbers and/or long-term thermocouple measurements are required. Their use should be accompanied by careful checks that the depth of immersion is adequate and that the total thermal loading does not exceed the capacity of the device. This may be achieved by monitoring the performance of one or two thermocouples used in the device, both with and without the full load of thermocouples, and comparisons can be made with their performance in an ice-bath.

4.3 The same remarks apply to reference junction boxes which may take the form of an insulated box containing reference junctions whose temperature is monitored by a thermometer either at ambient or a temperature provided by a thermostatically controlled heater. The effectiveness of the box's thermometer and controller should be checked periodically.

4.4 Cold-junction compensation is widely used in electronic temperature controllers and indicators. Electronic compensation modules are available either mains or battery powered. These are not very well suited to systems using large numbers of thermocouples and a separate module is normally required for each junction.

4.5 If a reference temperature other than 0 °C is used with a thermocouple having a calibration referenced to 0 °C, **the emf corresponding to the reference temperature chosen** shall be added to the measured emf output of the thermocouple.

5 Initial inspection

5.1 Thermocouples are available in various forms of insulation and protective sheathing as well as in 'bare-wire' form. Initial inspection will therefore depend upon their construction and use. Obvious signs of mechanical defects, contamination, etc. shall be recorded and the client informed if the laboratory feels that the validity or uncertainty of measurement in the calibration could be impaired. Any presence of moisture, particularly around compensating/extension lead connections, shall be investigated as this may reduce the leakage resistance and/or lead to the generation of emfs by electrolytic action. Measurement of the insulation resistance is a convenient method to identify any moisture within the thermocouple.

6 Heat treatment

6.1 Every thermocouple which shall be calibrated should be homogeneous. Inhomogeneous thermocouples used under conditions different from which they were calibrated, especially different temperature gradients, will give erroneous results which could amount to systematic deviations of several degrees Celsius.

6.2 Heat treatment/annealing of a thermocouple should be seen as a kind of 'adjustment' and, in the case of recalibrations, such heat treatment should only be carried out with the formal agreement of the client.

6.3 For the best results, a thermocouple to be calibrated should first be annealed at maximum immersion at the highest temperature of intended use. Type K thermocouples, which are subject to calibration changes on temperature cycling to 500 °C or above, should be calibrated at increasing temperatures, and the first calibration point repeated at the end as a check. The same considerations apply to a lesser extent to other base-metal thermocouples.

7 Thermal sources

7.1 Thermocouples are calibrated by measurement either at a series of fixed point temperatures, e.g. melting/freezing points or, by comparison with reference/standard thermometers, in thermally stabilised baths or furnaces suitable for the calibration, or by a combination of techniques, e.g. comparisons and fixed-point temperatures. Fixed-point(s) and standard thermometer(s) shall be traceable to national standards. Generally, fixed point calibrations are only required for the calibration of platinum-rhodium thermocouples at the highest accuracy.

7.2 A thermally stabilised bath or furnace suitable for calibration is one in which spatial temperature profiling using two or more standard thermometers at usually the mid-point and both ends of the working temperature range and within the working volume has been shown to be within required limits. The inclusion of this profile in the calibration certificate may help resolve immersion problems, although the profile in furnaces can depend greatly on the dimension of the thermocouple.

7.3 Temperature gradients within thermally stabilised baths or furnaces can be reduced or minimised by the insertion of a metal equalising block drilled with thermowells to receive the standard and test instruments. Such a block is not always necessary for example in multi-zone controlled furnaces and, without a block, stabilisation may be achieved more quickly.

7.4 In liquid-filled baths, thermocouples should be loaded with a separation of about 1 cm and should not contact the enclosure bottom or sides which might be at a slightly different temperature from the liquid.

7.5 Standard and test thermocouples can be protected from contamination in the furnace by inserting them in close-fitting thin-walled recrystallised alumina tubes with closed ends. However, longer immersion may be needed to compensate for the poorer thermal coupling.

8 Immersion depth

8.1 When possible, thermocouples should be calibrated at the same immersion as required in normal use. However, thermocouples shall be immersed to a depth sufficient to overcome heat losses or gains at high and low temperatures, respectively. Such effects are induced by large diameter wires, thick walled insulators, and sheaths. Where possible a thermocouple should be progressively immersed into a controlled calibration enclosure until further immersion shows no change in the measured emfs indicating that an appropriate immersion depth has been reached. In some circumstances, sheaths and linings may need to be removed and lighter more suitable insulator substituted.

8.2 These considerations apply to both comparison and fixed-point calibrations. A steady emf may be obtained, but this does not necessarily mean that the correct temperature has been reached. Adequate immersion is only demonstrated if the change in emf on withdrawing the thermocouple one or two centimetres is small compared with the required uncertainty of measurement in the calibration.

9 Measurement procedure

9.1 In fixed point measurements, it is prudent to measure the melting or freezing point of each realisation of temperature with a reference standard thermocouple which should be dedicated for this purpose. An erroneous or false plateau can arise with the use of three-term temperature controllers which may hold the furnace very precisely near, but not at the fixed-point temperature. It is important, therefore, to witness the melting/freezing curve, and the undercool that precedes the temperature rise to the freezing point arrest.

9.2 In comparison calibrations, it is advisable to use two standards which provide for a cross check of one another and the calibration system. To reduce the effects of drift in the thermal source, the following measurement sequence should be followed:

$S_1, X_1, X_2 \ldots. X_n, S_2, S_2, X_n \ldots. X_2, X_1, S_1$

where S_1 and S_2 are the two reference standards and X_1, X_2 .... X_n are the thermocouples to be calibrated.

This sequence may be repeated to give four measurements on each instrument. The mean values are calculated and any corrections (for example, due to voltmeter calibration) are applied. The temperature is taken to be the mean value calculated from the results of S1 and S2.

10 Electrical measurements

10.1 Electrical measurements are normally made using digital voltmeters or direct reading temperature indicators. Manual potentiometers are now rarely used but because of their long term stability they can be useful for cross-reference and checking purposes. All electrical measurement systems shall be traceably calibrated over the whole of the required emf/temperature range.

10.2 Manual switchgear and dials on selector switches, reversing switches and manual potentiometers should be gently exercised on a daily basis through about twenty movements to clear oxide films and possible contact resistance.

10.3 When the closest accuracies are required measurements should be made of both forward and reverse polarities by means of a reversing switch. The average value of the measurements eliminates or minimises the effect of the stray thermal emfs in the measuring system. Stray emfs can arise at any point in the measuring circuit where there is a change of temperature and at the juncture of dissimilar metals, e.g. copper wires and brass terminals. Suitable shielding and/or lagging and control of the ambient temperature should be provided. Digital voltmeters can behave differently in the positive and negative modes so both polarities shall be calibrated if reversals shall be made. The measuring circuit can be checked (and corrected) for any residual emfs by measurement of the circuit when it is closed by short-circuiting at the thermocouple connection terminals.

11 Recalibration

11.1 There are no formally specified frequencies for the recalibration of thermocouples because their types, temperature ranges, construction, application, intensity of use are so numerous and varied. It shall be expected that an in-house quality management scheme evolves a checking and recalibration programme to meet with its requirements and experience.

11.2 Where there are long-term installations of thermocouples, calibration checks are best made in situ by providing for the insertion of a standard alongside the working thermocouple(s) as and when required. Alternatively, a thermocouple can be temporarily substituted for a standard thermocouple and their emfs compared. In practice, a programme of periodic replacement may be preferred.

11.3 A change in the emfs and calibration of a thermocouple as the result of use, or even as the immediate result of calibration, can be quantified by immersing the thermocouple in a thermally stabilised bath or furnace held at an appropriate temperature and measuring the output at a series of immersion depths spanning the normal working depth. If, finally, the thermocouple is substantially over-immersed, i.e. beyond any previous working depth, the measured emfs should closely approximate the value shown on the (first) calibration certificate at the corresponding temperature and corroborate the validity of the two (possibly different) calibration systems.

11.4 For base-metal thermocouples, a replacement with a calibrated thermocouple rather than a recalibration is often the best solution. Otherwise 'in-situ' calibration or checks are advised. Careful heat treatment can sometimes improve inhomogeneity.

12 Reporting results

12.1 The calibration certificate in which the results of the measurements are reported should be set out with due regard to the ease of assimilation by the user's mind to avoid the possibility of misuse or misunderstanding.

12.2 The certificate shall meet the requirements of EAL publication EAL-R1 [8].

The technical content should comprise the following:

(a) a clear identification of the items subjected to measurement including the thermocouple(s), any compensating or extension cables especially when these are separate items and any other instruments (e.g. digital indicators) that form part of the whole measured system;

(b) the temperature range covered by the calibration;

(c) a statement of any heat treatment carried out before the calibration;

(d) the depth of immersion of the sensor, possibly together with a temperature profile of the temperature source(s) used in the calibration;

(e) the measurement procedure used (e.g. 'fixed' points, comparison with standard sensor(s)), increasing or decreasing calibration temperatures;

(f) any relevant environmental conditions;

(g) any standard or other specification relevant to the procedure used (e.g. ITS-90 reference tables);

(h) an evaluation of the uncertainty of measurement associated with the results.

13 Uncertainty of calibration

13.1 Uncertainties of measurement shall be calculated in accordance with EAL publication EAL-R2 'Expression of the Uncertainty of Measurement in Calibration' [9]. An example calibration showing likely sources of uncertainty is given in the appendix.

14 Bibliography

1 American Society For Testing And Materials : *Manual on the use of thermocouples in temperature measurement.* ASTM Special Technical Publication 470A. Philadelphia

2 Quinn, T. J. : *Temperature.* Academic Press : London, 1983

3 Nicholas, J V ; White, D R : *Traceable Temperatures.* John Wiley & Sons Ltd : Chichester, England, 1994.

4 BIPM : *Techniques for Approximating the International Temperature Scale of 1990.* 1990.

5 Burns, G. W. ; et al : *Temperature-Electromotive Forces Reference Functions and Tables for the Letter-designated Thermocouple Types Based on the ITS-90,* NIST Monograph 175, US Dept of Commerce, 1993

6 IEC 584-1 : 1995 (EN 60584-1 : 1996). *Thermocouples, Part 1, Reference tables*

7 IEC 584-3 : 1989. *Thermocouples, Part 3, Extension and Compensating Cables — Tolerances and Identification System.*

8 EAL-R1 : 1995. *Requirements Concerning Certificates Issued by Accredited Calibration Laboratories.*

9 EAL-R2 : 1997. *Expression of the Uncertainty of Measurement in Calibration.*

Appendix A

Example of an uncertainty budget

A1 Calibration of a type N thermocouple at 1000 °C

A1.1 A type N thermocouple is calibrated by comparison with two reference thermocouples of type R in a horizontal furnace at a temperature of 1000 °C. The emfs generated by the thermocouples are measured with a digital microvoltmeter through a selector/reversing switch. All thermocouples have their reference junctions at 0 °C. The test thermocouple is connected to the reference point using compensating cables.

A1.2 The temperature of the hot junction of the test thermocouple is

$$\begin{aligned} t_X &= t_S(V_{iS} + \delta V_{iS1} + \delta V_{iS2} + \delta V_R - \frac{\delta t_{0S}}{C_{S0}}) + \delta t_D + \delta t_F \\ &\cong t_S(V_{iS}) + C_S \cdot \delta V_{iS1} + C_S \cdot \delta V_{iS2} + C_S \cdot \delta V_R - \frac{C_S}{C_{S0}} \delta t_{0S} + \delta t_D + \delta t_F \end{aligned} \quad \text{(A1.1)}$$

The voltage across the test thermocouple wires with the cold junction at 0 °C during the calibration is

$$V_X(t) \cong V_X(t_X) + \frac{\Delta t}{C_X} - \frac{\delta t_{0X}}{C_{X0}} = V_{iX} + \delta V_{iX1} + \delta V_{iX2} + \delta V_R + \delta V_{LX} + \frac{\Delta t}{C_X} - \frac{\delta t_{0X}}{C_{X0}} \quad \text{(A1.2)}$$

where

$t_S(V)$	temperature of the reference thermometer in terms of voltage with the cold junction at 0 °C. The function is given in the calibration certificate.
V_{iS}, V_{iX}	indications of the voltmeter;
δV_{iS1}, δV_{iX1}	voltage corrections due to the calibration of the voltmeter;
δV_{iS2}, δV_{iX2}	voltage corrections due to the resolution of the voltmeter;
δV_R	voltage correction due to contact effects of the reversing switch ;
δt_{0S}, δt_{0X}	temperature corrections due to the reference temperatures;
C_S, C_X	sensitivity coefficient of the thermocouples for voltage at the measuring temperature of 1000 °C;
C_{S0}, C_{X0}	sensitivity coefficient of the thermocouples for voltage at the reference temperature of 0 °C;
δ_{tD}	drift of the reference thermometers since last calibration;
δt_F	temperature correction due to non-uniformity of the furnace;

t	temperature at which the test thermocouple is to be calibrated (calibration point);
$\Delta t = t - t_X$	deviation of the temperature of the calibration point from the temperature of the furnace;
δV_{LX}	voltage correction due to the compensation leads.

A1.3 The reported result is the output emf of the test thermocouple at the temperature of its hot junction. Because the measurement process consists of two steps — determination of the temperature of the furnace and determination of emf of the test thermocouple — the evaluation of the uncertainty of measurement is split in two parts.

A1.4 **Reference standards:** The type R reference thermocouples are supplied with calibration certificates that relate the temperature at their hot junctions with their cold junction at 0 °C to the voltage across their wires. The expanded uncertainty of measurement at 1000 °C is $U = 0{,}3\ °C$ (coverage factor $k = 2$).

From previous calibrations, the drift of the values of the reference standards is estimated to be zero within the limits of 0,3 °C.

A1.5 **Voltage sensitivity coefficients:** The voltage sensitivity coefficients of the reference and test thermocouples have been taken from reference tables.

	1000 °C	0 °C
reference thermocouple	$C_S = 0{,}077$ °C/µV	$C_{S0} = 0{,}189$ °C/µV
unknown thermocouple	$C_X = 0{,}026$ °C/µV	$C_{S0} = 0{,}039$ °C/µV

A1.6 **Resolution and calibration of the voltmeter:** A 4½ digit microvoltmeter has been used in its 10 mV range, resulting in resolution limits of 0,5 µV at each indication. The voltmeter has been calibrated and respective corrections to the measured voltages are made to all results. The calibration certificate gives a constant expanded uncertainty of measurement of U = 2,0 µV for voltages below 50 mV (coverage factor $k = 2$).

A1.7 **Parasitic voltages:** Residual parasitic offset voltages due to the switch contacts have been estimated to be zero within ±2 µV.

A1.8 **Reference temperatures:** The temperature of the reference point of each thermocouple is known to be 0 °C within ±0,1 °C.

A1.9 **Temperature gradients:** The temperature gradients inside the furnace have been measured. At 1000 °C, deviations from non-uniformity of temperature in the region of measurement are within ±1 °C.

A1.10 **Compensation leads:** The compensation leads have been tested in the range 0 °C to 40 °C. Voltage differences between the leads and the thermocouple wires are estimated to be less than 5 µV.

A1.11 **Observations:** The voltmeter indications have been read in the following operational procedure, which gives four readings for every thermocouple and reduces the effects of temperature drift in the thermal source and of parasitic thermal voltages in the measuring circuit:

1st cycle:
1st standard, test thermocouple, 2nd standard, 2nd standard, test thermocouple, 1st standard.

Reversion of polarity.

2nd cycle:
1st standard, test thermocouple, 2nd standard, 2nd standard, test thermocouple, 1st standard.

The procedure requires the difference between the two reference standards not to exceed 0,3 °C. If the difference is not within these limits the observations have to be repeated and/or the reasons for such a large difference have to be investigated.

Thermocouple	**1st reference**	**Test**	**2nd reference**
Indicated voltage, corrected	+10500 μV	+36245 μV	+10503 μV
	+10503 μV	+36248 μV	+10503 μV
	-10503 μV	-36248 μV	-10505 μV
	-10504 μV	-36251 μV	-10505 μV
Mean voltage	10502,5 μV	36248 μV	10504 μV
Temperature of the hot junction	1000,4 °C		1000,6 °C
Temperature of the furnace		1000,5 °C	

A1.12 From the four readings on each thermocouple, one observation of the mean voltage of each thermocouple is deduced. The mean voltages of the reference thermocouples are converted to temperature observations by means of temperature voltage relations given in their calibration certificates. These temperature values are highly correlated. By taking the mean, they are combined into one observation of the temperature of the furnace at the location of the test thermocouple. In a similar way, one observation of the voltage of the test thermocouple is extracted. In order to evaluate the uncertainty of measurement associated with these observations, a series of ten measurements has been previously undertaken at the same temperature of operation which gave pooled estimates of the standard deviation for the temperature of the furnace and the voltage of the thermocouple to be calibrated.

The resulting standard uncertainties of measurement are:

pooled estimate of standard deviation: $s_p(t_S) = 0{,}10\ °C$

standard uncertainty: $u(t_S) = \frac{s_p(t_S)}{\sqrt{1}} = 0{,}10\ °C$

pooled estimate of standard deviation: $s_p(V_{iX}) = 1{,}6\ \mu V$

standard uncertainty: $u(V_{iX}) = \frac{s_p(V_{iX})}{\sqrt{1}} = 1{,}6\ \mu V$

A1.13 **Uncertainty budget (temperature of the furnace):**

quantity X_i	estimate x_i	standard uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(y)$
t_S	1000,5 °C	0,10 °C	normal	1,0	0,10 °C
δV_{iS1}	0 µV	1,00 µV	normal	0,077 °C/µV	0,077 °C
δV_{iS2}	0 µV	0,29 µV	rectangular	0,077 °C/µV	0,022 °C
δV_R	0 µV	1,15 µV	rectangular	0,077 °C/µV	0,089 °C
δt_{0S}	0 °C	0,058 °C	rectangular	-0,407	-0,024 °C
δt_S	0 °C	0,15 °C	normal	1,0	0,15 °C
δt_D	0 °C	0,173 °C	rectangular	1,0	0,173 °C
δt_F	0 °C	0,577 °C	rectangular	1,0	0,577 °C
t_X	1000,5 °C				0,641 °C

A1.14 **Uncertainty budget (emf of the thermocouple to be calibrated):**

quantity X_i	estimate x_i	standard uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(y)$
V_{iX}	36 248 µV	1,60 µV	normal	1,0	1,60 µV
δV_{iX1}	0 µV	1,00 µV	normal	1,0	1,00 µV
δV_{iX2}	0 µV	0,29 µV	rectangular	1,0	0,29 µV
δV_R	0 µV	1,15 µV	rectangular	1,0	1,15 µV
δV_{LX}	0 µV	2,9 µV	rectangular	1,0	2,9 µV
Δt_X	0,5 °C	0,641 °C	normal	38,5 µV/°C	24,5 µV
δt_{0X}	0 °C	0,058 °C	rectangular	-25,6 µV/°C	-1,48 µV
V_X	36 229 µV				25,0 µV

A1.15 Expanded uncertainties

The expanded uncertainty associated with the measurement of furnace temperature is

$U = k \times u(t_X) = 2 \times 0{,}641\ °C \cong 1{,}3\ °C$

The expanded uncertainty associated with the emf value of the thermocouple to be calibrated is

$U = k \times u(V_X) = 2 \times 25{,}0\ \mu V \cong 50\ \mu V$

A1.16 Reported result

The type N thermocouple shows, at the temperature of 1000,0 °C, with its cold junction at a temperature of 0 °C, an emf of 36 230 μV ±50 μV.

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor $k = 2$, which for a normal distribution corresponds to a coverage probability of approximately 95 %.